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WATSUN SIMULATION LABORATORY ANNUAL REPORT: PHASE III, FOR THE PERIOD APRIL 1989 - MARCH 1990

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WATSUN SIMULATION LABORATORY ANNUAL REPORT: PHASE III, FOR THE PERIOD APRIL 1989 - MARCH 1990

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Le Laboratoire de simulation WATSUN (LSW) a toujours eu pour objectif de fournir à l'industrie, au gouvernement et aux autres organismes de recherche des progiciels WATSUN améliorés. Au LSW, nous nous efforçons d'atteindre cet objectif par la poursuite d'activités de recherche et de développement axées sur de nouveaux modèles de simulation des systèmes héliotechniques, par la prestation de services de soutien technique lié à ces nouveaux modèles, lesquels services s'adressent à l'industrie, au gouvernement et aux autres organismes de recherche, et par la poursuite d'activités visant à tenir à jour et à diffuser les programmes logiciels WATSUN, de même qu'à faciliter l'utilisation de ces programmes.

Cette année, notre temps et nos ressources ont été partagés presque à parts égales entre les programmes WATSUN Thermal et WATSUN-PV. Au cours des premiers mois de l'année, nous avons lancé la version 11.1 de WATSUN, comportant des corrections apportées à la version 11.0. Depuis, ce programme a subi un grand nombre de modifications, en partie par suite de trois initiatives : un document de la SESCI portant sur la raccordement de panneaux en série et en parallèle, une visite aux installations de la societé Fournelle Energy Technologies, en mai, et un atelier sur la modélisation des systèmes héliotechniques, au Colorado, en juin. Une nouvelle version 12.0 de WATSUN sera lancée sous peu.

On a lancé la version 2.0 de WATSUN-PV, y compris de nouveaux modèles de courbes I-V pour les cellules et les piles. Pour autant que nous sachions, il s'agit du premier progiciel de simulation au monde à inclure un modèle de démonstration de piles thermosensibles. On a presque terminé la mise au point de la version 3.0 de WATSUN-PV, comprenant un modèle hybride avec cellules photovoltaïques et générateur diesel et un modèle avec cellules photovoltaïques et pompe à eau. Cette version sera lancée d'ici le milieu de l'été de 1990.

Au cours de l'année dernière, on a vendu cinq copies de WATSUN et quatre du WATSUN-PV, ce qui a fait passer le nombre total de clients à 43. Les utilisateurs de l'extérieur qui communiquent avec le VAX sont actuellement si peu nombreux que nous avons cessé de facturer les clients pour leur durée de liaison. Le LSW s'est maintenant procuré un puissant micro-ordinateur IBM et, par conséquent, il pourra vendre le VAX d'ici la fin de 1990.

Les dépenses totales liées à WATSUN étaient inférieures de 155 849 $ au montant du contrat de cette année. Les recettes produites dépassaient de 4 000,98 $ les dépenses.

WSL ANNUAL REPORT
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1 EXECUTIVE SUMMARY

It has been the continuing objective of the WATSUN Simulation Laboratory to provide industry, government, and other research organizations with improved WATSUN software packages. At WSL we try to do this by researching and developing new models for simulating solar energy systems, by providing technical support for these new models to industry, government, and otner research organizations, and by continuing to maintain, distribute, and facilitate the use of the WATSUN software programs.

Time and resources were split approximately equally this year between WATSUN Thermal and WATSUN-PV. In the early part of the year, WATSUN 11.1 was released, containing some corrections to WATSUN 11.0. The program has undergone a large number of changes since then, partly as a result of three initiatives: a SESCI paper on series versus parallel panel connections, a visit to Fournelle Energy Technologies in May, and a solar energy modelling workshop in Colorado in June. A new version of WATSUN, 12.0, will be released shortly.

WATSUN-PV 2.0 has been issued, including new I-V models for the arrays and the batteries. To the best of our knowledge, this is the first simulation package in the world to include a functioning temperature-sensitive battery model. WATSUN-PV 3.0, including a PV/Diesel Hybrid model and a PV Water Pumping model, is in the advanced stages of development, and will be issued by mid-summer, 1990.

In the past year 5 copies of WATSUN and 4 copies of WATSUN-PV have been sold, bringing the total clientele to 43. So few outside users link to the VAX now that we have discontinued invoicing clients for their connect time. The WSL has now acquired a powerful IBM micro-computer, so that by the end of 1990 the VAX can be sold.

WATSUN's total spending was $155,849 under the contract for the year. Income generated exceeded expenses by $4000.98.

2 PROGRAMS

The WATSUN Simulation Lab distributes two main computer programs, the WATSUN thermal program and WATSUN-PV. These programs are available for VAX computers, IBM-compatibles, and the Apple Macintosh. Demonstration packages for each program have also been produced.

2.1 WATSUN Thermal

The officially available version of WATSUN through most of this year has been WATSUN 11.1 (see Appendix B). However, a new version was in development, with a large number of added features, as detailed in Section 3 WATSUN Thermal Projects. As the program evolved, WATSUN 11.A, 11.D, 11.2, and 11.3 were all

produced, primarily for use in house. Several copies of WATSUN 11.3 were given to outside users who had particular need for the new features. As a result, the new version has been extensively tested.

Towards the end of the contract year, a new manual was written, in preparation for officially issuing WATSUN 12.0. This manual was still in the word-processing stage by the end of March, but the program itself was ready.

2.2 WATSUN-PV

WATSUN-PV 1.0 was still available through most of this contract year, but WATSUN-PV 2.0, with a manual, was issued during the fourth quarter of the year (see Appendix B).

The algorithms for WATSUN-PV 3.0 have been developed, including new models for PV/Diesel Hybrid and Water Pumping systems. A substantial amount of the program has also been written and it is partially working. The issuing date for WATSUN-PV 3.0, with a manual, is expected to be mid-summer, 1990.

2.3 MacWATSUN and MacWATSUN-PV

A new compiler for FORTRAN on the Macintosh has recently been acquired. It is more reliable than the compiler we were using previously, which has now gone out of production. The new compiler makes it considerably easier to issue the Macintosh versions of the programs simultaneously with the IBM versions.

After some experience with using the Macintosh, we can not recommend running math-intensive programs like WATSUN on a Macintosh without a mathematics co-processor (e.g. a Mac Plus or SE). Run-time is very long on these machines, so we strongly recommend that a Mac II or at least a Mac SE/30 be used. Macintosh users who are daunted by the need to spend more money on a machine with a co-processor should be aware that the programs also run very slowly on an IBM-compatible without a co-processor.

2.4 Demonstration Packages

Demonstration diskettes for WATSUN 11.1 and WATSUN-PV 1.0 are still available. We have not yet prepared demonstrations for the new versions. We are planning to produce a more simplified demo version this time, with more of the mathematics removed, in order to make them easier to write and more compact.

The demonstration diskettes are mailed free of charge to potential customers who request them. The package also includes a portion of the manual so that the user will have some instructions on how to operate the program, as well as some general information about the program. Several sales have resulted.

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3 WATSUN THERMAL PROJECTS

The WATSUN thermal program has undergone a considerable amount of development in the past year. Several new features were added at the request of Fournelle Energy Technologies in Montreal. They funded a visit by the WATSUN manager to their plant, which greatly speeded up the development process.

A workshop held at Colorado State University in June prompted several more changes to WATSUN. This workshop brought together most of the people working on solar energy simulation, from Canada, the U.S., and Europe, to test the various IEA Task VI models against each other. The somewhat competitive atmosphere, as well as the general sharing of expertise, sparked a major effort to improve WATSUN.

The new features were included in WATSUN 11.3, which was not officially released because the manual was not ready. Some copies were distributed to customers with a particular need for them, without documentation. This has proven to be an effective way of testing the new features, as these "beta" users have discovered a number of errors which we have corrected. Thus, WATSUN 12.0, when it is issued, will be free of the minor bugs sometimes associated with a large program change. The manual for WATSUN 12.0 has been written and is now in the word-processing stage.

3.1 Series/Parallel Connection of Collector Panels

Most solar energy systems requiring several solar panels have the panels connected in series, or at least partially in series. Users of WATSUN with panels that exhibit nonlinear performance characteristics are concerned that the simulation results should show the difference in performance expected when such panels are connected in series instead of in parallel.

A new version of WATSUN, 11.A, was created with series connection equations for the DHWO and DHWS models. This was based on the equations in section 7.6 of Duffie and Beckman (D & B). Testing of this system of equations produced results showing a degradation of performance when collectors were connected in series, even for flat plates. This unexpected result was presented in a paper at SESCI '89, but it was apparent that more work was required to establish if the series equations were working correctly with other parts of the program.

In late May the series equations had been extended to include the other 11 systems in WATSUN 11.3, an in-house version for testing new models for later release. During the solar modelling workshop in Fort Collins, CO, discussions with Craig Christiansen of SERI cleared up the problem with our equations for series connection. Section 7.6 of D & B is a re-working of the adjustment of collector performance for different flowrates, in section 6.1 of D & B. Thus WATSUN 11.A and 11.3 were carrying out one calculation in two different ways. Once this was corrected, in July (see second quarter report), WATSUN 11.3 gave expected results: series and parallel connections make no difference for flat

plate collectors, as long as the number and type of collectors remain the same, and the total flowrate is equal. A slight change in performance is experienced with nonlinear collectors, because of the high entry temperatures experienced by collectors towards the end of the series.

3.2 Multiple Panel Types

WATSUN 11.A also included the capability of including two sets of differing panels connected in series. For example, a set of flat plate panels could be used to preheat the water for a set of more expensive high performance panels. This feature has been extended to all the systems in WATSUN 11.3. An additional convenience of this system is that a user with two common types of collectors can input the parameters for one in the first collector block, and the other in the second collector block. Then either type of panel can be used, with the number of collectors of the other type set to zero.

This is a feature that may not prove useful to a large number of users. After it is released as part of WATSUN 12.0, a user survey will have to be done to find out if people want it to stay in future versions.

3.3 Minimum Collector Outlet Temperature

This feature was added during the manager's visit to Fournelle in Montreal. It is an addition to the collector controller which shuts off the collector pump if a specified minimum collector outlet temperature cannot be reached.

3.4 Maximum Heater Power

Previous versions of WATSUN included an auxiliary heater of infinite capacity, which would always meet the required load, if the collector did not produce enough energy. The Sunswitch* system, added to WATSUN in 1985, contained an auxiliary heater of limited capacity. This enabled the user to determine the effect of inadequate system capacity on the actual load delivered.

During the visit to Fournelle, the limited heater capacity was extended to all the other systems. An additional feature of the Sunswitch system permits load volume to be increased by some factor, if lower quality energy is acceptable. This means that if the auxiliary heater cannot provide energy at the desired load temperature, the same quantity of energy will be supplied, but at a lower temperature and a higher volume. This feature has been extended to the other systems along with the limited heater capacity. By default, of course, the feature is turned off, by setting the maximum factor for load flowrate increase to 1.

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*Sunswitch is a trademark of NORSUN Corporation.

3.5 High Temperature Capability

In some markets, like India, there is a high demand for collectors that can deliver to a load at a temperature substantially above the boiling point of water. Some are pressurized so that the collector fluid remains liquid, while others involve a phase change. WATSUN was capable of modelling the pressurized type of system, as long as the specific heat of the collector fluid did not change appreciably with temperature.

During the visit to Fournelle, profiles were added to change both the specific heat of the collector fluid and the heat capacitance of the tank fluid with temperature, so that pressurized systems can be correctly modelled.

3.6 Boiling System

The problem of phase change systems was a more difficult one, and could not be completed during the visit to Fournelle. It was undertaken back at the WATSUN lab, where colleagues from the Solar Thermal Research Lab were available for consultation. The resulting model is based on the DHWO, non-storage system. It is actually an approximation because the heat transfer mechanisms involved are not fully defined. The effect of boiling on the collector is accounted for by calculating the energy collected based on an inflated heat capacitance flowrate. This reflects the fact that heat transfer to a boiling fluid is very rapid. The results of the model appear reasonable, but must be compared to a real system in order to be validated.

3.7 Space Heating System

A rudimentary space heating system was added to WATSUN 11.3 at the request of Fournelle. This model is partly a revival of a system that existed in WATSUN versions 5 and 6, but it has also been changed substantially. It is a simple system, with no heat exchangers. Heat is transferred to the room by simply placing the storage tank, uninsulated, in the room to be heated. The building to be heated is a single room with no windows, a fixed infiltration rate, and a constant heat gain from people or machines inside it. The results report average room temperature and time below the minimum, as well as sources of heat gain and loss. The model has not been officially released yet, but has already proved useful to three other users. It has therefore been included in WATSUN 12.0, soon to be released.

3.8 Pump Power Fraction

In previous versions of WATSUN, all pump power in the collector loop was added to the collector fluid as an energy gain. In order to satisfy one of the

requirements of the solar modelling workshop in Colorado, this feature was added to allow a specified fraction of pump power to be added to the collector fluid while the rest is released to the environment as heat.

3.9 Additional Temperature Controllers

Another feature added for the solar modelling workshop was a set of Tco controllers. If the collector outlet temperature drops below a certain temperature above the inlet temperature, the collector shuts off. It does not turn on again until Tco rises to the specified value above inlet temperature. The Tc-Tci (plate temperature minus inlet temperature) controller remains in place as before.

3.10 European Collector Performance Description

The Europeans have a different 5-parameter model than WATSUN has traditionally used. For a nonlinear collector, $F_R(\tau\alpha)_e$ remains fixed with temperature, while F_RU_L is calculated based on the following equation:

$$F_RU_L = b + c(Tci) - d(Ta)$$

In order to satisfy the requirements of the solar modelling workshop, this capability was added to WATSUN, so that now it can use either 5-parameter model.

3.11 Indoor and Outdoor Piping

Previous versions of WATSUN assumed that all collector piping was outside, losing heat to the ambient temperature. Another feature added for the modelling workshop was the capability to include some indoor piping, which would lose (or gain) energy to and from the building.

3.12 Side-arm Heat Exchanger Model

During a visit to University of Waterloo in 1988, Mr. Theo van der Meer of the Technological University of Delft in The Netherlands, developed a finite volume analysis program for a shell-and-tube side-arm heat exchanger. This program calculates the heat transferred by the heat exchanger under various conditions of temperatures and flowrates, given an input file describing the physical characteristics of the exchanger.

The program typically takes 2 days of CPU time running on our VAX, so it is not something we anticipate transferring to the PC or Macintosh. However, it will produce an ASCII output file with complete performance information for the exchanger. This file can be moved to another computer and used as an input by WATSUN 11.3. Note also that any other exchanger can be described

in the same detail by a similar analysis program or by experiment, and as long as the data is provided in the same format as the files from Mr. van der Meer's program, WATSUN 11.3 can use it to model that exchanger.

3.13 Shape of Storage Tanks

During some experimentation involving large numbers of WATSUN runs with different storage tank sizes, it became obvious that the method for specifying tank shape is very time-consuming. Onerous calculations of wall and floor areas must be carried out for every small change in tank volume. The new version therefore, includes the aspect ratio (height/diameter) and a shape factor for the floor that relates floor perimeter to floor area. If the tank remains the same shape, neither number needs to change if the volume changes.

3.14 Collector Plate Conditions

IEA Task 10 included a study of corrosion of collector plate materials. To this end, an earlier testbed version of the program, WATSUN 10.D, was created to simulate the conditions of temperature and humidity experienced by the collector plate. As the main program developed, WATSUN 10.D was updated to 11.D. Finally, the plate conditions feature was added to version 11.3 as an option. When WATSUN 12.0 is issued, users will be able to simulate the temperature and humidity experienced by the collector plate during the simulation period, and print out a table showing the time spent under each set of conditions.

3.15 System Failure

The collector plate experiences much greater extremes of temperature if a failure occurs which disrupts flow through the collector loop. A feature included in WATSUN 10.D, 11.D, and now 11.3, is the ability to specify a failure of a certain length beginning on a specified day of the year. The collector plate temperature and humidity report will then include the stagnation conditions for that period.

3.16 WATSUN Graphing

An undergraduate research assistanceship was given to Philip Zwart from mechanical engineering, to develop a macro for LOTUS-123 that the WATSUN program can activate in order to graph its results. The resulting program is a good start at the problem. The user can now plot the numbers in the monthly summation, with any column versus any other column, or with one column versus the month. Only one plot can appear on each graph, but any number of graphs can be made from the same output listing.

WATSUN 12.0 and WATSUN-PV 3.0 will both include graphing capability. However, this applies only to the IBM-PC compatible version of the program, and it will only work for users who also have a copy of LOTUS-123. Fortunately, 70% of spreadsheet users on IBM-compatibles use LOTUS. For those who use other spreadsheets, such as Quattro, we have been told that these packages can use macros written for LOTUS-123 with very few modifications. These modifications (and who will pay for them to be made) will be a matter for discussion with individual clients. We are intending to produce a version for Excel on the Macintosh, because 70% of spreadsheet users on the Macintosh use Excel. This should be completed during the next contract year.

3.17 Documentation Update

In preparation for the issuing of WATSUN 12.0 and the updating of the manual, another run of the variable dictionary package was run. The variable dictionary process often reveals mistakes in a program, such as units errors or misspelled variables. However, because a run was done just before the release of WATSUN 11.1, this time the process uncovered very few errors. It also took only a few days to do the whole project, because most of the variables were previously defined. Now all the new areas of the program are properly documented, to enable other programmers to familiarize themselves with WATSUN much more easily.

3.18 WATSUN Manual

The manual for WATSUN 12.0 has been written and is being word-processed. It has been delayed because of a switch in the word-processing equipment used. The earlier manuals were prepared on a MICOM, which was borrowed from Waterloo Research Institute. We are now using LOTUS Manuscript on one of our own computers. Because of the large number of equations and other special formatting, the text could not be simply transferred over, and had to be re-typed. The new manual is expected to be approximately 500 pages long when printed. The WATSUN 12.0 manual will be printed on Save-a-Tree Copy Paper, which is made from 50% de-inked waste paper.

3.19 Testing of IEA Task VI Models Against WATSUN

The WATSUN manager and principle investigator attended a workshop in Colorado in June to compare the IEA Task VI simulation tools available from around the world. WATSUN was found to compare favourably in terms of accuracy, flexibility, and ease of use. In ease of use, WATSUN is comparable to F-Chart, while the answers it gives are similar to those of TRNSYS, a much more complex program. In execution time and computer resource requirements, it offers an effective compromise. Part of the final report of this workshop is included in Appendix D.

3.20 Preparation and Presentation of Design Workshop

A guide for designing solar energy systems using WATSUN was developed by Dr. Chandrashekar to supplement an extensive DOE document on solar design using simulation programs. A one-day design workshop was developed and run at the ASES meeting in Colorado in June. Participants were introduced to a number of software tools for design of solar heating and cooling systems, including WATSUN and other IEA Task VI programs. Several worked examples and data sheets were prepared so that users could have a hands-on experience of running the programs.

4 WATSUN PHOTOVOLTAIC PROJECTS

The development of WATSUN-PV 2.0 was the primary responsibility of a co-op student, Karl Rueb, who was at WSL for four months of this contract year. After his departure at the end of August, the task of continuing development devolved to the manager. Most of the manager's time during the third quarter was devoted to producing a working version of WATSUN-PV 2.0. Part of this work was the actual integration of the new battery model into the rest of the program, followed by several iterations of improvements to meet the standards of Steve Dixon and John Savage, our "alpha" users. Subsequently, a new variable dictionary was created, and then the new manual was written.

4.1 Array Model

The old array model with WATSUN-PV 1.0 was a power model. In order to better fit it to the new battery and load models, a true I-V model was needed. This improved model would not only fit the rest of the program better, but would also provide a more realistic model of the actual working of the array, and allow more sophisticated array control models. This was begun in co-operation with Steve Dixon of TDS Dixon and was completed during the second quarter. By the end of August, a true I-V model was completed and working well. Two array control strategies, maximum power point tracking and battery controlled array voltage, were both included.

4.2 Battery Model

Early in this contract year, problems were found with the battery model provided by ORTECH. Results were not reasonable, but it was initially thought that some debugging and minor improvements would make the model usable. The process of debugging revealed that the battery equations did not remain stable during the solution process for an hour. The WATSUN lab programmer attempted to find an improved solving algorithm that would keep these equations under control. However, this approach had not been successful by the end of the summer work-term.

In the third week of August a meeting was held at the offices of TdS Dixon to discuss progress. John Savage represented ORTECH, Steve Dixon represented TdS, and Dave Shipley and Karl Rueb represented WSL. It became clear during the meeting that serious flaws were still present in the battery model at that stage, and that upon Karl Rueb's departure to continue his studies a major programming task would devolve upon Dave.

A change in philosophy was required first. ORTECH had developed a model based on a number of internal battery parameters that would be calculated based on their tests. It became clear that these intermediate parameters, such as internal voltage and impedance, were an unnecessary step in the calculation of battery performance based on test results. A better approach would be to develop a large curve fitting algorithm based on battery charge and discharge information. The temperature, current, and existing state of charge would be inputs to the model and voltage would be an output.

By the end of September a working battery model had been developed, separate from the rest of the PV model. This program could read in a series of charge and discharge curves from a data file and develop from them a set of equations for carrying out the four-dimensional curve fit. The user could then input temperature, current, and existing state of charge, and the voltage would be returned. A considerable amount of work remained to fit the new battery model into the rest of the program.

4.3 Integration of the Battery Model into WATSUN-PV 2.0

Once true I-V models existed for all the components we were to incorporate into a SABB model for WATSUN-PV, making them work together under the various operating strategies and regulator types we intended to include required a great deal of work. The superstructure above the I-V models that iterates between them to settle on correct system voltages and currents is extensive and complex, and it is beyond the scope of this report to discuss it in detail. The reader is asked to refer to chapter 6 of the WATSUN-PV 2.0 manual for further discussion.

4.4 PV/Diesel Hybrid Model

The battery model developed for WATSUN-PV 2.0 has the big advantage of being easy to incorporate into another type of system, since it is a true I-V model of the batteries. Therefore, it has been a relatively simple matter to develop the algorithms for a hybrid system. Modifications were required for the control structure in the program, but the solution process is still largely the same. The AC/DC and DC/AC converters are specified in terms of their efficiency, and the diesel engine is specified with a curve of performance versus load.

4.5 PV Water Pumping

The equations for the water pumping model have been developed and tested in a LOTUS-123 spreadsheet and are partially implemented in WATSUN-PV 3.0. Since this system does not include batteries, it will be relatively simple and will have much shorter run-time than the other systems in WATSUN-PV.

4.6 Documentation Update

As with the thermal program, it was necessary to create a variable dictionary for WATSUN-PV. This had not been done before with this program, and as a result it uncovered some bugs which were good to find before the program was to be issued. The process also helped greatly with subsequent manual writing.

4.7 WATSUN-PV Manual

The writing of the WATSUN-PV 2.0 manual was completed before the end of the third quarter, and word processing was completed by February. At that point WATSUN-PV 2.0 was officially released to existing customers, and will be sent out to new customers as they subscribe.

5 SHARED PROJECTS

5.1 Tracking

The addition of collector tracking to the WATSUN program was begun at the modelling workshop at Colorado State University in June. At that time, the two-axis tracker and the azimuth (fixed slope) tracker were completed, but the general case of a one-axis tracker with the axis in the plane of the collector was not. Work on this feature continued in July, based on the equations in "Solar Geometry for Fixed and Tracking Surfaces" by J.E. Braun & J.C. Mitchell (Solar Energy, Vol. 31, No. 5). It has now been completed, and is included in WATSUN 12.0 and WATSUN-PV 2.0.

5.2 Economics

The economic model included in earlier versions of WATSUN could only run when the simulation period was exactly one year. It provided only the net present worth calculations and life cycle costing. There are a wide variety of other methods for comparison of the economics of different energy systems, as detailed in the IEA publication "A Review of Economic Analysis Methcdologies" (IEA-SHAC-W1, October 1985). The new economic model in WATSUN now includes, in addition to the present worth and life cycle costing, the annual worth, the benefit/cost ratio, the actual rate of return, and the discounted and discounted

cash flows, indicating time of payback. The new economic model will also work with simulation periods longer or shorter than one year. This economic model is used in both WATSUN 12.0 and WATSUN-PV 2.0.

5.3 Radiation

Some work was done in this quarter on integrating A. Brunger's diffuse radiation model into the WATSUN program. While some improvements have been made to the diffuse model used in WATSUN 11.3, we have not incorporated the fully anisotropic sky model. This is because the runtime for the anisotropic model was 20-30 minutes on the VAX (usually a factor of at least 10 should be used to calculate runtime on an IBM-XT with co-processor). Even this is a substantial improvement over the runtime of 4 hours that we saw at first. Further work will be carried out to bring runtime to a reasonable value before this model will be included in the program. The improvements made so far to the radiation model for the thermal program will also be included in WATSUN-PV.

6 CLIENTS/USAGE

As can be seen from the BASE Contract expenditures statement (Appendix A), use of the WATSUN programs through linking to the microVAX has become obsolete. Most of our clients have purchased a WATSUN program to be used on an IBM PC or compatible and access to the microVAX is only necessary for a version of the program which has not been officially released.

WATSUN's total client base stands at 43, with a gradual shift taking place as a few thermal clients depart and a new PV clients are gained. Some clients have purchased multiple copies of the program. For example, Fournelle has 6 copies of it, some of which have been distributed to their sales representatives.

7 EQUIPMENT

Because of a surplus in the budget at the end of the 1989-90 contract year, the WATSUN Simulation Lab was able to purchase some urgently needed computing equipment. Through the university computer store, we obtained a substantial discount on an IBM PS/2 Model 80 25 Mhz 80386-based machine, with a 120 MB hard drive, in an easily expandable tower configuration. It has been equipped with three different floppy drives to produce programs on any format of diskette required by the users. Money was also made available from Dr. Chandrashekar's NSERC grant for the purchase of a 20 MHz 386 "clone", for the use of WSL co-op students.

With these two computers available, three of the aging computers in the lab are immediately made obsolete. Two of them, a TATUNG AT-compatible and an IBM-XT, were purchased under earlier NSERC grants and can therefore be sold to

replenish some of the money spent on the 386 clone. The third computer, a 12-year-old IBM-PC, belongs to the crown and will be disposed of according to the government's instructions.

By the end of 1990, we plan to install suitable hardware and software in the PS/2 to enable it to take over all the tasks presently carried out by the MicroVAX. At that point the VAX will be put up for sale. Although it is a crown asset, we are hoping that the proceeds can be used to pay for the added hardware that the PS/2 will require to support multi-user functions, as well as to help upgrade some of our other equipment. In order to be compatible with our main Macintosh-based customer, Thermo Dynamics, we should upgrade our Mac to an SE/30. We also need a good printer for the production of manuals.

Thus, by the end of 1990, we will have disposed of two old IBM micros, a TATUNG, the VAX, and the Rainbow which is presently used as a terminal for the VAX. The remaining computers in the lab will be the IBM PS/2, a 386 clone, and an upgraded Macintosh SE/30. The result will be fewer computers, with more reliability and lower maintenance costs.

8 TRAVEL

Dave spent a week in May at Fournelle Energy Technology in Montreal providing consulting and technical support for the WATSUN thermal program.

In June, Dave along with our co-op student, attended the SESCI Conference in Penticton, BC. At the conference they presented a paper entitled "Comparison of Solar Water Heating Systems with Series Parallel Collectors of Two Types using WATSUN" which was jointly written with M. Chandrashekar. (See Appendix C).

Staff from WATSUN attended the PV design workshop at the SESCI Conference in Penticton in order to gain an improved understanding of the practical aspects of PV system design.

Immediately following the SESCI Conference, Dave went on to assist in a workshop offered as part of the SOLAR '89 Conference in Denver, Colorado. The purpose of the workshop was for testing IEA Task VI models. Other participants in the workshop included Professor W.S. Duff of Colorado State University, M. Chandrashekar, and several members of the solar community in the U.S. and Europe. (See Appendix D).

At the end of March, Dave went to Madison, Wisconsin to do some work with Ruth Urban, the manager of the TRNSYS program. The problems to be solved are often very similar for the two programs, and it was felt that much duplication of effort could be avoided by working together. Improvements should result in the WATSUN radiation model, the PV array model, and the user interfaces for both programs. One particular advantage to this trip was the opportunity to compare programming tools used by both labs.

9 CASH FLOW

Please refer to Appendix A for details.

9.1 Sales

		Thermal	PV	Total
First Quarter	-	1	1	2
Second Quarter	-	2	2	4
Third Quarter	-	2	1	3
Fourth Quarter	-	-	-	-
TOTAL	-	5	4	9

9.2 Spending and Revenue

First Quarter	-	$33,588.67 (21.55%)
Second Quarter	-	$46,840.64 (30.05%)
Third Quarter	-	$29,435.31 (18.88%)
Fourth Quarter	-	$45,984.38 (29.51%)
TOTAL	-	$155,849.00 (99.99%)

Almost the entire budget allotted for this contract year has been used as can be seen from the chart.

Expenses (labour, materials & supplies, computer, travel)

$2,910.28 (1st quar.)
790.97 (2nd ")
1,311.35 (3rd ")
-158.58 (4th ")

$4,854.02 (total expenses)

Income (program sales, subscription renewals, sales of weather files)

$2,235.00 (1st quar.)
1,910.00 (2nd ")
2,200.00 (3rd ")
2,510.00 (4th ")

$8,855.00 (total income)
-4,854.02 (total expenses)

$4,000.98 (net income)

APPENDIX A - Quarterly Statements of Accounts

WATSUN USER SERVICE

BASE CONTRACT EXPENDITURES: Period 01 April '89 to 30 June '89 (1st quarter)

LABOUR	$18,358.05
MATERIALS & SUPPLIES	$ 2,006.76
DIRECT COSTS	$ 1,291.13
EQUIPMENT	$
TRAVEL/LIVING	$
OVERHEAD	$11,932.73
TOTAL	$33,588.67

Representing 21.55 % of annual budget.

Prepared for WATSUN User Service

by C A Kesselitter

date Sept 26/89

WATSUN USER SERVICE

NET INCOME STATEMENT: Period April 1, 1989 to June 30, 1989 (1st quarter)

INCOME

Small Contracts:	1. _____	$ _____	
	2. _____	$ _____	
	3. _____	$ _____	
	4. _____	$ _____	
	5. _____	$ _____	$ _____
Link-Based Users:			$ NIL
Sales of WATSUN Program & Manuals:			$ 2.235.00
Registrations - Courses/Seminars/Workshops:			$ _____
Other: _____ :			$ _____
TOTAL			$ 2,235.00

EXPENSES

Labour	$ 726.99
Materials/Supplies	$ 653.43
Computer	$ _____
Travel/Living	$ 1529.86
TOTAL	$ 2,910.28

TOTAL NET INCOME: ... ... $ (675.28)

Statement prepared for WATSUN User Service

by C. Kennedy

Date Sept 26/89

WATSUN USER SERVICE

LINK BASED USER REVENUE STATEMENT:

User	1st quarter	2nd quarter	3rd quarter	4th qu
Advanced Scientific Computing Ltd.	$	$	$	$
Alberta Agriculture				
Arizona State University				
Ascent Engineering				
Bantle Engineering				
Batec				
Canadian Climate Centre				
Cdn. Solar Ind. Assoc. Inc.	85.00			
Centre for Building Studies				
Cogeneration Associates				
Coles Associates				
Colorado State University				
Conserval Engineering Inc.				
Dick & Price Engineering Ltd.				
Diemaco (1984) Inc.				
Dorfmuller				
DRB Engineering Consultant				
D.W. Thomson Consultants Ltd.				
E.A. Mueller	50.00			
E.J. Faraci & Associates				
Mr. Emilio Marcos Touche				
Energy, Mines & Resources				
Fournelle	1,900.00			
Indian Inst. of Technology				
INRS-Energies				
Negentrophy				
Network Energy Resources				
Northern Climate Engineering				
Northwest Tel				
Ontario Research Fdn.-NSTF				
Parasol Engineering				
Provincial Consultants				
Public Works and Highways				
Rockwell International				
Rose Technology				

WATSUN USER SERVICE

LINK BASED USER REVENUE STATEMENT:

	1st quarter	2nd quarter	3rd quarter	4th quar
Ruesch Sonnentechnils	$	$	$	$
SESCI-NAC				
Solamatic Systems				
Solar 2000 U.K.				
Solar Calorimetry Lab				
Solar Evaluation Services				
Solar Systems Industries				
Solarteam/OAR				
Solar Thermal Lab				
Solar Thermal Technology				
Solcan Ltd.				
Soltek				
Southern Alta. Inst. of Technology				
Sun Direct Energy Inc.				
Sunglo Solar Ltd.				
TES Limited				
Thermodynamics				
University of Alberta				
University of Manitoba				
University of Saskatchewan				
University of New Brunswick				
	200.00			
T O T A L :	$2,235.00	$	$	$

Statement prepared for WATSUN User Service

by C. Kesselring

date Sept 26/89

WATSUN USER SERVICE

BASE CONTRACT EXPENDITURES: Period 01 July 1989 to 30 September/89 (2nd quarter)

LABOUR	$ 19,750.79
MATERIALS & SUPPLIES (includes IEA workshop $9,440.00)	$ 11,067.72
DIRECT COSTS	$ 734.34
EQUIPMENT	$
TRAVEL/LIVING	$ 2,401.75
OVERHEAD	$ 12,886.04
TOTAL	$ 46,840.64

Representing 30.05 % of annual budget.

Prepared for WATSUN User Service

by Cheryl Kieswetter

date October 13, 1989

WATSUN USER SERVICE

NET INCOME STATEMENT: Period July 1, 1989 to September 30, 1989 (2nd quarter)

INCOME

Small Contracts:	1. _____	$ _____	
	2. _____	$ _____	
	3. _____	$ _____	
	4. _____	$ _____	
	5. _____	$ _____	$ _____
Link-Based Users:			$ _____
Sales of WATSUN Program & Manuals:			$ 1,910.00
Registrations - Courses/Seminars/Workshops:			$ _____
Other: _____ :			$ _____
TOTAL			$ 1,910.00

EXPENSES

Labour	$ _____	
Materials/Supplies	$ 734.46	
Computer	$ _____	
Travel/Living	$ 56.51	
TOTAL		$ 790.97

TOTAL NET INCOME: $ 1,119.03

Statement prepared for WATSUN User Service
by Cheryl Kieswetter

Date October 13, 1989

WATSUN USER SERVICE

LINK BASED USER REVENUE STATEMENT:

User	1st quarter	2nd quarter	3rd quarter	4th q
	$	$	$	$
Advanced Scientific Computing Ltd.				
Alberta Agriculture				
Arizona State University				
Ascent Engineering		100.00		
Bantle Engineering				
Batec		100.00		
Canadian Climate Centre				
Cdn. Solar Ind. Assoc. Inc.	85.00			
Centre for Building Studies				
Cogeneration Associates				
Coles Associates				
Colorado State University				
Conserval Engineering Inc.				
Dick & Price Engineering Ltd.				
Diemaco (1984) Inc.				
Dorfmuller				
DRB Engineering Consultant				
D.W. Thomson Consultants Ltd.				
E.A. Mueller	50.00			
E.J. Faraci & Associates				
Mr. Emilio Marcos Touche				
Enermodal		60.00		
Fournelle	1,900.00	100.00		
Indian Inst. of Technology				
INRS-Energies		100.00		
Negentrophy				
Network Energy Resources				
Northern Climate Engineering				
Northwest Tel				
Ontario Research Fdn.-NSTF				
Parasol Engineering				
Provincial Consultants				
Public Works and Highways		125.00		
Rockwell International				
Rose Technology				

WATSUN USER SERVICE

LINK BASED USER REVENUE STATEMENT:

	1st quarter	2nd quarter	3rd quarter	4th quarter
Ruesch Sonnentechnils	$	$	$	$
SESCI-NAC				
Solamatic Systems				
Solar 2000 U.K.		100.00		
Solar Calorimetry Lab				
Solar Evaluation Services				
Solar Systems Industries				
Solarteam/OAR				
Solar Thermal Lab		200.00		
Solar Thermal Technology				
Societe d'Etude de l'Env.		400.00		
Seastar Instruments Ltd.		125.00		
Southern Alta. Inst. of Technology				
Sun Direct Energy Inc.				
Sunglo Solar Ltd.				
TES Limited				
Thermodynamics		100.00		
University of Alberta				
University of Manitoba		100.00		
University of Saskatchewan				
University of New Brunswick	200.00			
Nu-Tec Eng. Ltd.-		100.00		
Ortech		100.00		
Technologia Solar		100.00		
T O T A L :	$2,235.00	$1,910.00	$	$

Statement prepared for WATSUN User Service,
by Cheryl Kieswetter
date October 13, 1989

WATSUN USER SERVICE

BASE CONTRACT EXPENDITURES: Period 01 Oct./89 to 31 Dec./89 (3rd quarter)

LABOUR	$ 16,565.84
MATERIALS & SUPPLIES	$ 1,602.42
DIRECT COSTS	$ 499.25
EQUIPMENT	$ -
TRAVEL/LIVING	$ -
OVERHEAD	$ 10,767.80
TOTAL	$ 29,435.31

Representing 18.88 % of annual budget.

Prepared for WATSUN User Service

by Cheryl Kieswetter

date Feb. 16, 1990

WATSUN USER SERVICE

NET INCOME STATEMENT: Period 01 Oct./89 to 31 Dec./89 (3rd quarter)

INCOME

Small Contracts:	1. _____	$ _____	
	2. _____	$ _____	
	3. _____	$ _____	
	4. _____	$ _____	
	5. _____	$ _____	$ _____
Link-Based Users:			$ _____
Sales of WATSUN Program & Manuals:			$ 2,200.00
Registrations - Courses/Seminars/Workshops:			$ _____
Other: _____ :			$ _____
T O T A L			$ 2,200.00

EXPENSES

Labour	$ 1,109.97	
Materials/Supplies	$ 129.09	
Computer	$ _____	
Travel/Living	$ 72.29	
T O T A L		$ 1,311.35

T O T A L N E T I N C O M E : ... ... $ 888.65

Statement prepared for WATSUN User Service
by Cheryl Kieswetter

Date Feb. 16, 1990

WATSUN USER SERVICE

LINK BASED USER REVENUE STATEMENT:

User	1st quarter	2nd quarter	3rd quarter	4th qua
Advanced Scientific Computing Ltd.	$	$	$	$
Alberta Agriculture				
Arizona State University				
Ascent Engineering		100.00		
Bantle Engineering				
Batec		100.00		
Canadian Climate Centre			100.00	
Cdn. Solar Ind. Assoc. Inc.	85.00		100.00	
Centre for Building Studies			100.00	
Cogeneration Associates				
Coles Associates				
Colorado State University				
Conserval Engineering Inc.				
Dick & Price Engineering Ltd.			200.00	
Diemaco (1984) Inc.				
Dorfmuller				
DRB Engineering Consultant				
D.W. Thomson Consultants Ltd.			100.00	
E.A. Mueller	50.00		100.00	
E.J. Faraci & Associates				
Mr. Emilio Marcos Touche				
Enermodal		60.00		
Fournelle	1,900.00	100.00		
Indian Inst. of Technology				
INRS-Energies		100.00		
Negentrophy			100.00	
Network Energy Resources				
Northern Climate Engineering			60.00	
Northwest Tel				
Ontario Research Fdn.-NSTF				
Parasol Engineering				
Provincial Consultants			200.00	
Public Works and Highways		125.00	100.00	
Rockwell International				
Rose Technology				
Thermodax Ind.			100.00	
XRG Consultants Inc.			60.00	
Solar Innovations			100.00	

WATSUN USER SERVICE

LINK BASED USER REVENUE STATEMENT:

	1st quarter	2nd quarter	3rd quarter	4th quar
	$	$	$	$
Ruesch Sonnentechnils				
SESCI-NAC				
Solamatic Systems				
Solar 2000 U.K.		100.00		
Solar Calorimetry Lab				
Solar Evaluation Services			100.00	
Solar Systems Industries				
Solarteam/OAR			100.00	
Solar Thermal Lab		200.00	60.00	
Solar Thermal Technology			100.00	
Societe d'Etude de l'Env.		400.00	60.00	
Seastar Instruments Ltd.		125.00		
Southern Alta. Inst. of Technology				
Sun Direct Energy Inc.				
Sunglo Solar Ltd.				
TES Limited				
Thermodynamics			100.00	
University of Alberta		100.00		
University of Manitoba			100.00	
University of Saskatchewan		100.00	100.00	
University of New Brunswick	200.00			
Nu-Tec Eng. Ltd.		100.00		
Ortech		100.00		
Technologia Solar		100.00	60.00	
T O T A L :	$2,235.00	$1,910.00	$2,200.00	$

Statement prepared for WATSUN User Service,

by Cheryl Kieswetter

date February 16, 1990

WATSUN USER SERVICE

BASE CONTRACT EXPENDITURES: Period 01 January /90 to 31 March /90 (4th quarter)

LABOUR	$ 19,794.66
MATERIALS & SUPPLIES	$ 812.22
DIRECT COSTS	$ 706.99
EQUIPMENT	$ 11,804.00
TRAVEL/LIVING	$ ---
OVERHEAD	$ 12,866.51
TOTAL	$ 45,984.38

Representing 29.51 % of annual budget.

Prepared for WATSUN User Service

by Cheryl Kieswetter

date May 8/90

WATSUN USER SERVICE

NET INCOME STATEMENT: Period 01 January 1990 to 31 March 1990 (4th quarter)

INCOME

Small Contracts:	1. _____	$ _____	
	2. _____	$ _____	
	3. _____	$ _____	
	4. _____	$ _____	
	5. _____	$ _____	$ _____
Link-Based Users:			$ _____
Sales of WATSUN Program & Manuals:			$ 2,510.00
Registrations - Courses/Seminars/Workshops:			$ _____
Other: _____ :			$ _____
TOTAL			$ 2,510.00

EXPENSES

Labour	$ ---
Materials/Supplies	$ (158.58)
Computer	$ ---
Travel/Living	$ ---
TOTAL	$ (158.58)

TOTAL NET INCOME: ... ... $ 2,668.58

Statement prepared for WATSUN User Service

by Cheryl Kieswetter

Date May 8/90

WATSUN USER SERVICE

LINK BASED USER REVENUE STATEMENT:

User	1st quarter	2nd quarter	3rd quarter	4th quar
	$	$	$	$
Advanced Scientific Computing Ltd.				100.00
Alberta Agriculture				100.00
Arizona State University		100.00		
Ascent Engineering				990.00
Astro Power Canada Ltd.		100.00		
Batec			100.00	100.00
Canadian Climate Centre	85.00		100.00	
Cdn. Solar Ind. Assoc. Inc.			100.00	
Centre for Building Studies				
Cogeneration Associates				
Coles Associates				
Colorado State University				100.00
Conserval Engineering Inc.				
Dick & Price Engineering Ltd.			200.00	
Diemaco (1984) Inc.				
Dorfmuller				
DRB Engineering Consultant				
D.W. Thomson Consultants Ltd.			100.00	
E.A. Mueller	50.00		100.00	
E.J. Faraci & Associates				
Mr. Emilio Marcos Touche				
Enermodal		60.00		
Fournelle	1,900.00	100.00		300.00
Indian Inst. of Technology				
INRS-Energies		100.00		
Negentrophy			100.00	
Network Energy Resources				
Northern Climate Engineering			60.00	100.00
Northwest Tel				100.00
Ontario Research Fdn.-NSTF				
Parasol Engineering				
Provincial Consultants			200.00	
Public Works and Highways		125.00	100.00	
Rockwell International				
Rose Technology				
Thermodax Ind.			100.00	
XRG Consultants Inc.			60.00	100.00
Solar Innovations			100.00	

WATSUN USER SERVICE

LINK BASED USER REVENUE STATEMENT:

	1st quarter	2nd quarter	3rd quarter	4th quar
Ruesch Sonnentechnils	$	$	$	$ 20.00
SESCI-NAC				
Solamatic Systems				100.00
Solar 2000 U.K.		100.00		
Solar Calorimetry Lab				100.00
Solar Evaluation Services			100.00	
Solar Systems Industries				
Solarteam/OAR			100.00	
Solar Thermal Lab		200.00	60.00	
Solar Thermal Technology			100.00	
Societe d'Etude de l'Env.		400.00	60.00	
Seastar Instruments Ltd.		125.00		
Solcan Ltd.				100.00
Sun Direct Energy Inc.				100.00
Sunglo Solar Ltd.				
TES Limited				
Thermodynamics			100.00	
University of Alberta		100.00		
University of Manitoba			100.00	
University of Saskatchewan		100.00	100.00	
University of Nova Scotia				100.00
University of New Brunswick	200.00			
Nu-Tec Eng. Ltd.		100.00		
Ortech		100.00		
Technologia Solar		100.00	60.00	
T O T A L :	$2,235.00	$1,910.00	$2,200.00	$2,510.00

Statement prepared for WATSUN User Service

by Cheryl Kieswetter

date March 8, 1990

APPENDIX B - New Version Release Notes

** NEW RELEASE ** NEW RELEASE ** NEW RELEASE ** NEW RELEASE **

Please find enclosed new diskettes and manual pages for our latest WATSUN thermal program -- version 11.1.

There is once again only four diskettes for this version instead of the five for 11.0 and installation is back to normal (instructions enclosed).

Changes to the manual have also been made and can be found on the list enclosed.

Should you have any questions regarding this new program, please do not hesitate to contact us.

******

Also, announcing WATSYN 2.0. A synthetic weather program available at a purchase price of $60.00

WATSUN User Service, University of Waterloo, Waterloo, Ontario N2L 3G1 Telephone (519) 885-6160
Computer address: WATSUNA@WATDCS.NETNORTH

WATSUN 11.1 -- MANUAL REVISIONS

Revisions to the User's manual include:-

Chapter 1, Section 1.1.1 - NEW LOGON PROCEDURES for link access of WATSUN

Section 1.1.2 - now DATAPAC Access Refused

Chapter 3, Section 3.7 - Stratified Tank Data Block
A few additions (K6-8) to the data block. These are explained in the Parameter Descriptions.

Section 3.8 - Sunswitch System Data Block
H1-H5 are additions to this data block and are explained under Parameter Descriptions.

Section 3.9 - Heat Exchanger Data Block
A note has been added after parameters 1 & 4 in the Parameter Descriptions.

Section 3.15 - Swimming Pool Data Block A
The data block has been revised -- A6 & A7 are new. They are explained in the Parameters Descriptions

Section 3.16 - Swimming Pool Data Block B
B7, B12, and B16 have been added to this data block and are described in the Parameter Descriptions.

Section 3.20 - Preheat Tank Data for Each ...
F7 has been added and is explained in the Parameter Descriptions.

* * * * * ANNOUNCING WATSUN-PV 2.0!!!! * * * * *

This version contains a new array model, with arrays modelled as an I-V curve instead of just a power source. It also includes the temperature dependent battery model, which returns battery voltage given the temperature, current, and existing state of charge. Battery modelling is based on a series of charge and discharge curves specified by the user in units of voltage versus hours, as well as information on battery gassing. These tests can be carried out by the user or by ORTECH. Some battery manufacturers may also be able to provide suitable results.

A wide variety of additional features are provided, as detailed in the accompanying manual. Questions, comments, and suggestions will be welcome. Version 3.0 is expected in the near future, so many of your ideas could be included. Version 3.0 will include a model for a diesel backup generator and for a PV water pump.

Runtime for this version is somewhat slow, but most of you have much faster computers than I do, so it should be on the order of 15 minutes. Better-behaved systems run faster. If you are significantly gassing the battery for a large part of the summer you will find that runtime increases.

WATSUN User Service, University of Waterloo, Waterloo, Ontario N2L 3G1 Telephone (519) 885-1180
Computer address: WATSUNA@WATDCS.NETNORTH

APPENDIX C - Paper for SESCI 1989

COMPARISON OF SOLAR WATER HEATING SYSTEMS WITH SERIES AND PARALLEL COLLECTORS OF TWO TYPES USING WATSUN

D.F. Shipley, K.G. Rueb, M. Chandrashekar
WATSUN Simulation Laboratory
University of Waterloo

Abstract

Arrays of solar panels are usually connected in parallel and series arrangements, for practical reasons. Series connections have lower performance than parallel connections, and designers need to be able to model this effect. As well, it is useful to examine systems that use more than one type of collector, so that less expensive collectors can be used for initial warming and high performance collectors can be used to achieve higher temperatures. Investigation of these systems was carried out using a modified version of the WATSUN hour-by-hour computer simulation program. Three different sizes of system were considered in three Canadian locations. It was found that parallel arrangements of flat plate panels were optimal for half the scenarios studied. High performance characteristics were more important at higher energy prices, or when load temperatures were high, or in northern climates. Systems with parallel high performance panels were optimal in many of these cases, but there was also an intermediate region where the best system used parallel branches, each with one flat plate connected in series with a higher performance panel.

Introduction

Solar arrays with a large number of panels are commonly configured as several groups of panels connected in parallel, with each group containing a number of panels connected in series. The simplest mathematical model for multi-panel arrays assumes that all panels are connected in parallel. However, series connections do have the effect of reducing the efficiency of the solar array, because the high temperature of water reaching panels near the end of the series reduces their efficiency.

Some of the efficiency change caused by series connections can be reduced by altering flowrate. In order to use a simulation method to arrive at a correctly adjusted flowrate, however, the designer would need to have access to a model including both series and parallel connections.

Another potential arrangement with multi-panel arrays would be the use of more than one type of collector. For example, if a high load temperature is required, but the collectors capable of operating at this temperature are very expensive, less expensive collectors could be used to warm the fluid initially. It could then be sent through a small number of the expensive collectors.

In order to study the effects of series/parallel connections, and the use of more than one type of collector, a specialized version of WATSUN was created. This was used to model a small domestic system requiring only two panels, a medium sized system with 12 panels and a large system with 100 panels. In each case, the optimum arrangement was sought using series or parallel conections and two types of collectors: flat plate and high performance.

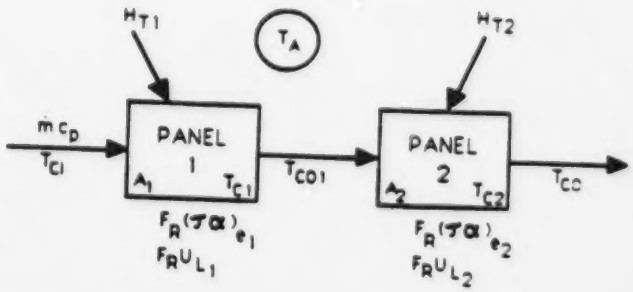
Economic criteria were used to determine the optimum configuration in each case. The economic conditions were varied, to find out when the high performance panels are financially competitive with the cheaper flat plate collectors. Simulations were carried out for several Canadian locations, including one site in the far north.

Theoretical Background for WATSUN Modification

The WATSUN program had to be modified to model collectors in series, and collectors of two types. For the general case of I x J collectors of type A followed by M x N collectors of type B, the program first assumes that an equivalent set of panels in series will have the same parameters and the same total area. Thus the system will now consist of J collectors of type A in series (each with I times its original area) followed by N collectors of type B in series (each with M times its original area).

Next the equivalent collector parameters are calculated to describe a single panel that is the equivalent of the type A group, with a total area of IJ times the area of one panel. A similar calculation is carried out for the B group. Finally the two large panels are combined into one equivalent panel.

To solve the general case of two different collectors connected in series, we assume the following diagram:



where: T_A = ambient temperature (C)

$\dot{m}c_p$ = capacitance flow rate (kJ/hr)

T_{CI} = collector inlet temperature (C)

T_{C1} = stagnation temperature of collector 1 (C)

T_{CO1} = outlet temperature of collector 1 (C)

T_{c2} = stagnation temperature of collector 2 (C)

T_{c0} = outlet temperature (C)

H_{T1} = radiation on collector 1 (kJ/hrm²)

H_{T2} = radiation on collector 2 (kJ/hrm²)

A_1 = area of collector 1 (m²)

A_2 = area of collector 2 (m²)

$F_R(\tau\alpha)_{e1}$ = gain parameter of collector 1

$F_R(\tau\alpha)_{e2}$ = gain parameter of collector 2

F_RU_{L1} = loss parameter of collector 1 (kJ/hrm²C)

F_RU_{L2} = loss parameter of collector 2 (kJ/hrm²C)

The equations for solving this case are derived from Duffie and Beckman, pp 269-70 (1980).

$$T_{c1} = T_a + H_{T1}(F_R(\tau\alpha)_{e1})/F_RU_{L1} \quad (1)$$

and

$$T_{c2} = T_a + H_{T2}(F_R(\tau\alpha)_{e2})/F_RU_{L2} \quad (2)$$

$$T_{ci1} = T_{ci} + \frac{A_1(F_RU_{L1})(T_{c1} - T_{ci})}{mc_p}_A \quad (3)$$

$$T_{c0} = T_{ci1} + \frac{A_2(F_RU_{L2})(T_{c2} - T_{ci1})}{mc_p} \quad (4)$$

Combining equations (1) through (4) yields:

$$T_{c0} = T_{ci} + \frac{(T_a - T_{ci})}{mc_p}[A_1F_RU_{L1}(1-K)] +$$

$$\frac{1}{mc_p}[A_1H_{T1}F_R(\tau\alpha)_{e1}(1-K) + A_2H_{T2}F_R(\tau\alpha)_{e2}] \quad (5)$$

where: $K = \frac{A_2F_RU_{L2}}{mc_p}$

If collector types 1 and 2 are the same, then:

$$T_{c0} = T_{ci} + \frac{A(T_a - T_{ci})}{mc_p}F_RU_L + \frac{AH_T}{mc_p}F_R(\tau\alpha)_e \quad (6)$$

where: $A = A_1 + A_2$

$$F_RU_L = \frac{A_1F_RU_{L1}(1-K) + A_2F_RU_{L2}}{A} \quad (7)$$

and

$$F_R(\tau\alpha)_e = \frac{A_1F_R(\tau\alpha)_{e1}(1-K) + A_2F_R(\tau\alpha)_{e2}}{A} \quad (8)$$

Finally, for N identical collectors connected in series:

$$F_RU_L = F_RU_{L1}\left[\frac{1-(1-K)^n}{NK}\right] \quad (9)$$

and

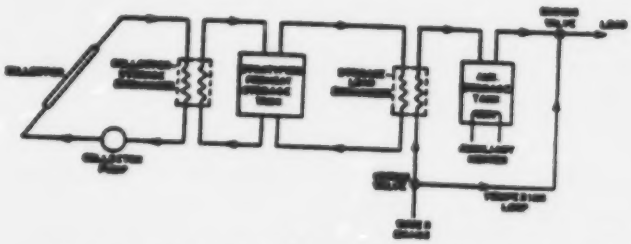
$$F_R(\tau\alpha)_e = F_R(\tau\alpha)_{e1}\left[\frac{1-(1-K)^n}{NK}\right] \quad (10)$$

where: $K = \frac{A_1F_RU_{L1}}{mc_p}$

Simulation Method

The three systems selected for simulation are all configured as in the WATSUN DHWS system shown in Figure 1. This includes a stratified preheat storage tank and a fully-mixed auxiliary tank. The stratification model for the preheat tank includes the recent modification for plume entrainment. Heat exchangers are not included in the system (they are entered as external exchangers with effectiveness of 1.0), because the fluid used throughout is water.

Figure 1. DHWS System Configuration



System A is a 2 panel system intended for the hot water requirements of a single family dwelling, with a load of 300 litres per day. System B is a 12 panel system intended for the hot water requirements of a small multi-family building, with a load of 2650 l/day. System C is a 100 panel system intended for a large multi-family building or an industrial system, with a load of 20,000 l/day.

Two types of panels were used in the simulations: a flat plate with fairly high loss characteristics ($F_R(\tau\alpha)_e$ = 0.75; F_RU_L = 5.0 kJ/hrm²C) and a cost of $125/m²; and a high performance panel with somewhat lower gain and significantly lower losses than the flat plate ($F_R(\tau\alpha)_e$ = 0.8914 - 5.142×10^{-4} x (Tci - Ta); F_RU_L = 0.8514 + 6×10^{-4} x (Tci - Ta) kJ/hrm²C). The cost of the high performance panels was initially set to $300/m², but a value of $200/m² was also used, to study the effect of price improvements on the cost competiveness of high performance panels.

Load temperatures were initially set to 60°C for all three systems. A higher load temperature of 80°C was also used, to test the hypothesis that high performance panels would be more cost competitive when high temperatures are required.

Simulations were run for three different sites, representing a variety of climatic zones in Canada. The three sites used were Toronto, Saskatoon, and Whitehorse.

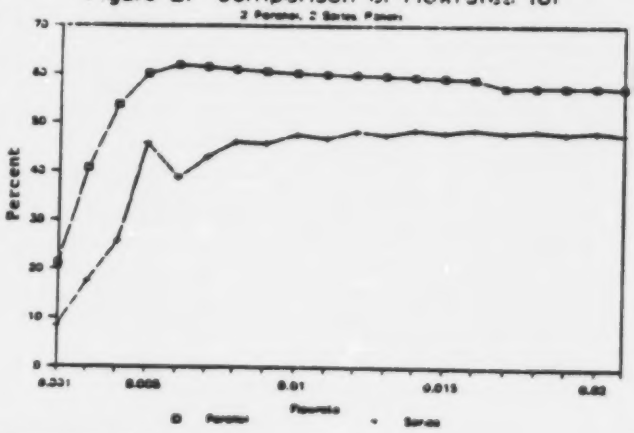
Energy price structures vary considerably within Canada. Cost per kWh of electricity can be as high as 25¢ in the Yukon. This translates into nearly $70/GJ of energy. At such a high cost for energy, every small improvement in system performance is likely to be very important. Simulations were therefore run for a variety of energy cost scenarios, starting with the base cost of $7/GJ and rising as high as $40/GJ.

Other economic assumptions made were as follows. Storage was assumed to cost $3,000/m³. Other fixed costs were $1,000 for System A, $6,000 for System B, and $40,000 for System C. The yearly maintenance costs were $50 for System A, $300 for System B, and $1,000 for System C. Systems were expected to last 20 years with no salvage value at the end. Interest rate and rate of return were 10%, and inflation was 5%.

For each configuration and location, an optimal system was determined, using the procedure set out in the flow chart in Figure 2. The example used is the 12 panel system, but essentially the same pattern was used for the smaller and larger systems. The first step in this approach was to compare two completely parallel systems, one with each type of collector. Then 3 different systems with 6 parallel series of 2 panels were tried, one with each type of collector panel

and one with both types. If no improvements were made this way, then the optimum was assumed to be one of the two completely parallel configurations. If an improvement was made, then more complicated series arrangements were tried.

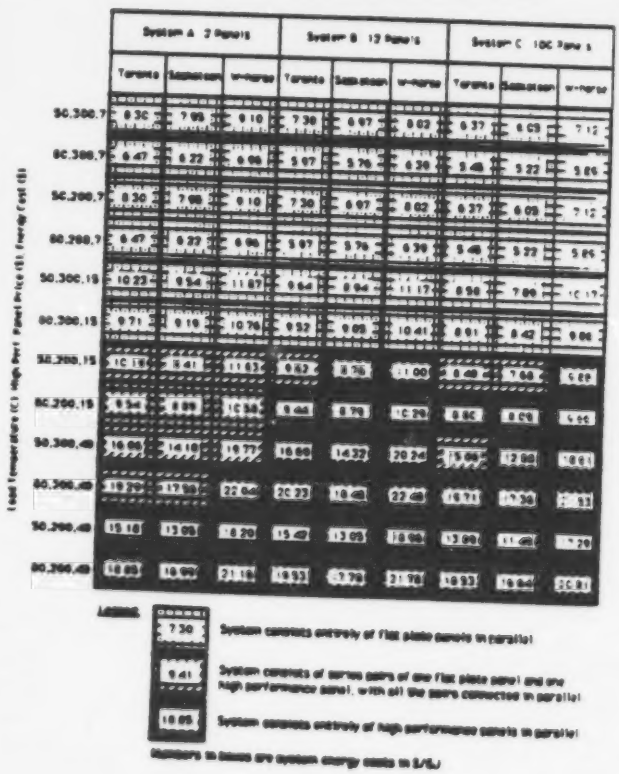
Figure 2. Comparison of Flowrates for



Discussion of Results

Table 1 summarizes the results obtained from simulating 108 different scenarios and determining the optimal system in each case. Prices shown in the individual squares of the table are the cost per GJ of energy, given the particular economic scenario. These prices are approximate, since the cost of energy and system components are chosen somewhat arbitrarily. However, the comparative prices between different scenarios are useful.

TABLE 1: Optimal System Configurations



Interestingly, for all 108 scenarios, only three types of systems were selected as optimal. In 64 of the scenarios, a system consisting entirely of flat plates in parallel was optimal. In 16 of the scenarios, the selected system consisted of series pairs of one flat plate panel and one high performance panel with all the pairs connected in parallel. In the remaining 28 scenarios, the system consisted entirely of high performance panels in parallel. There was a clear trend towards the high performance panels as energy became more expensive. Reducing the price of high performance panels also made them more likely to be selected, of course, but this effect was less significant than that of energy price.

As would be expected, the system cost of energy for Saskatoon is the lowest, because it has the highest insolation of the three cities. Whitehorse has the highest system energy cost of the three locations. Another distinguishable difference between the locations is that the systems with high performance panels out perform the systems with both types of panels more often in Whitehorse than in the other two cities. This shows that incremental improvements in performance are likely to be much more important in a northern climate

The high performance panels also tended to outperform the flat plate panels in situations where load temperature was high. This was expected, due to the fact that low loss characteristics would be more critical when operating temperature is high.

The three different sizes of systems performed in much the same way, although the smallest system seemed to favour a mixed flat plate/high performance system more often than either of the larger sizes did.

Table 2 shows the details for selection of the optimum for a 2 panel system, in Saskatoon, with 50°C load temperature, $300 high performance panels, and energy at $15/GJ, using the flowchart in Figure 3.

Figure 3 System Optimization Procedure

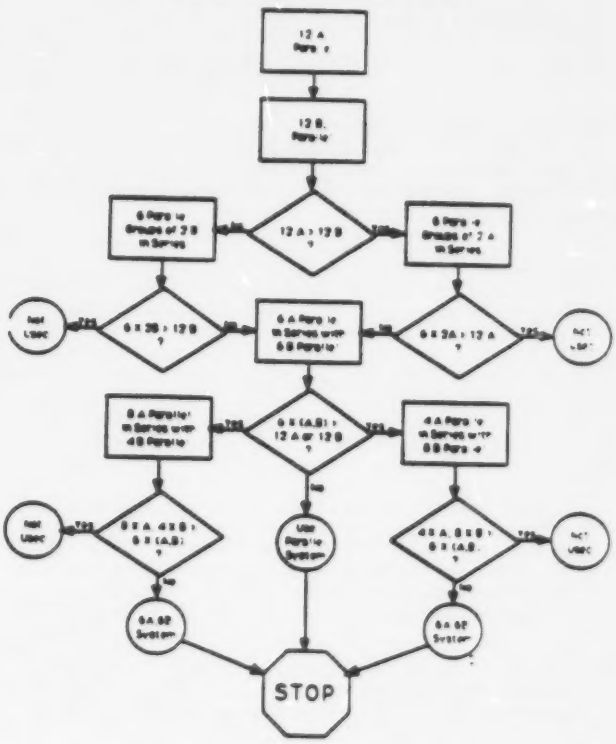


Table 2. Optimum 2 Panel System for Saskatoon with $15/GJ Energy

System	Fraction Solar	System Energy Cost
2 Flat Plates in Parallel	68.76%	$9.64/GJ
2 High Perf. in Parallel	78.73%	$11.24/GJ
2 Flat Plates in Series	52.66%	$11.19/GJ
1 Flat Plate and 1 High Perf. in Series	75.46%	$10.20/GJ

Clearly the high performance panels significantly improve the fraction solar for this system, whether they are used in series with the flat plate, or in parallel on their own. However, due to their higher cost, they do not out perform the flat plates economically for this scenario.

Following the same procedure with the energy cost changed to $40/GJ gives the following results:

Table 3. Optimum 2 Panel System for Saskatoon with $40/GJ Energy

System	Fraction Solar	System Energy Cost
2 Flat Plates in Parallel	68.76%	$14.51/GJ
2 High Perf. in Parallel	78.73%	$14.62/GJ
2 Flat Plates in Series	52.66%	$18.72/GJ
1 Flat Plate and 1 High Perf. in Series	75.46%	$14.10/GJ

The fraction solar is the same as in Table 2, because all the system parameters were the same except for auxiliary energy cost. However, in this case, the mixed system is the most economical, because the improved performance is more important when the energy price is higher.

Table 2 and 3 show that rearranging two panels from parallel to series involves a drop in fraction solar. This pattern was found for every system tested. For the two panel systems, each alternative was tested at a large number of different flowrates to determine the optimal flowrate for each arrangement of panels. Figure 2 shows the results for two parallel panels and for two series panels, located in Toronto, with load temperature of 60°C. As can be seen, there is no flowrate at which the series arrangement can achieve as high a fraction solar as the parallel system.

Conclusions

The ability to model systems with collectors in series as well as in parallel is important, because there is a significant drop in performance with series connections. The addition of this capability to WATSUN has permitted the theoretical effects of series connections to be calculated, which will be a valuable tool for designers who must optimize systems with panels in series.

The ability to model system with two types of collectors is also useful. The designer can use the program to decide which panels to use, or what combination of two types to use.

This study shows a clear trend towards high performance panels as energy gets more expensive and as the price of these panels drops. High performance panels are also more favoured when the load temperature is high or when the climate is harsh, as in northern Canada.

For half the scenarios studied, the parallel flat plate system was the best. In situations where performance was economically important, parallel high performance plates were optimal. In between there was an intermediate region where the best system used parallel branches each consisting of a flat plate panel in series with a high performance panel.

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